Continuous Monitoring of Structures for Landfill Gas Intrusion

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Closed, Illegal and Abandoned Site Program/California Integrated Waste Management Board

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This report was prepared by staff of the Integrated Waste Management Board to provide technical assistance to local governments and solid waste facility operators in investigating former landfills and disposal sites and in the installation, operation and maintenance of continuous gas monitoring systems. If you require assistance in obtaining access to this report, please contact the Public Affairs Office at (916) 341-6300.

Figure 1. Continuous Gas Monitoring Equipment

Abstract

Federal, State and local laws require that structures located on or near landfills and disposal sites be monitored for landfill gas migration to protect public health and safety from potential explosion hazards associated with methane gas. Continuous Gas Monitoring Systems, when carefully planned, designed, installed, operated, and maintained by qualified consultants and contractors, can provide an effective and economic mitigation measure to indoor landfill gas migration hazards. The Closed, Illegal and Abandoned (CIA) Site Program (http://www.ciwmb.ca.gov/LEACentral/CIA/) of the California Integrated Waste Management Board provides technical assistance to local governments in investigating former landfills and disposal sites in urban areas of the state. The CIA program is working on "high-priority" landfill investigations in many of the major population centers in California (Los Angeles, Orange County, San Diego, San Francisco Bay Area, etc.) and can provide field data, case studies, and lessons learned from investigations that may be helpful to other jurisdictions in managing their former landfills and disposal sites.

Key Words: *Landfill Gas Migration, Continuous Landfill Gas Monitoring, Fixed Gas Detection System, Catalytic & Infrared Gas Sensor, Wireless Transmitters and Receivers, Programmable Logic Control, Controllers, Data Loggers, Continuous Gas Monitoring Data.*

1. Introduction

The California Integrated Waste Management Board regulates former landfills and disposal sites in California to ensure that these sites do not pose a threat to public health and safety and the environment. With the growth and development of many California cities, many landfills and disposal sites that were formerly in outlying city areas have become encroached upon by development (and in some cases residential and commercial structures are located on the disposal area itself). A primary concern of landfills is the presence and movement of landfill gas, which is a by-product of landfill decomposition. Methane – a major component of landfill gas -- is explosive in concentrations between 5 and 15 percent by volume in ambient air. Landfill gas can migrate through permeable soils surrounding the landfill, and migrate into nearby structures and utilities.

California regulations require owners of former landfills and disposal sites to continuously monitor on-site structures for landfill gas migration and take corrective action if regulatory thresholds are exceeded. The technologies commonly used for continuous monitoring of combustible gases are infrared analyzer sensor technology or catalytic bead sensor technology. Combustible gas sensor technology was primarily developed by the oil and natural gas industry to monitor workplace environments and alert workers to potentially hazardous conditions (OSHA regulations: 29 CFR Section 1903, 1904, 1910 & 1926).

During the 1980s, energy monitoring and control systems necessitated the need for facility and utility operators to be able to track energy consumption of various mechanical and electrical equipment, e.g. pumps, heating and air conditioning equipment, etc. Direct Digital Control (DDC) technology, using computers and software interfaced with telecommunication systems and remote sensors, became a key element in managing energy consumption.

Today, continuous monitoring for landfill gas in structures, can utilize combustible gas sensors, direct digital control, programmable logic control and data acquisition systems to track the presence and concentrations of methane from landfill gas over time and provide the necessary data to document gas levels in structures that may pose a threat to public health and safety. Continuous monitoring can also provide data to a facility owner which can assist him in taking corrective measures to mitigate gas migration hazards, e.g. outside air ventilation, activation of gas collection and venting/control system, etc.

Phone modems can be used to remotely access continuous monitoring systems to check system status, data quality and also to download data; this has many advantages to include minimizing consultant or contractor time on-site (and subsequent costs) and also being able to detect and address system malfunctions in a timely manner.

Additionally new wireless technologies that allow 4-20 mA output from sensors can be converted to wireless transmissions (radio frequency) which allows sensor output measurements to be transmitted without the use of wire cables. This technology can greatly reduce the cost of installations, especially when excavation is required to bury cables in highly developed areas.

2. Regulations

Federal (40 CFR Part 258.23) and California State regulations (27 CCR 20921) require that landfill and disposal site owners control landfill gas migration if methane gas concentrations exceed 1.25 percent in on-site structures or 5 percent at the permitted perimeter boundary or an alternative boundary. California regulations regarding continuous monitoring of structures for landfill gas can be found in 27 California Code of Regulations (CCR), Section 20931 (http://www.ciwmb.ca.gov/Regulations/Title27/ch3sb4b.htm#Article6)

The following excerpts from 27 CCR, Chapter 3, Subchapter 4, Article 6: "Gas Monitoring and Control at Active and Closed Disposal Sites" are key requirements for continuous monitoring of structures for landfill gas:

Key Regulatory Language:

- 27 CCR 20919.5 (a) 1 Explosive Gas Control "…owners…must ensure that: (1) The concentration of methane gas generated by a (MSWLF) facility *does not exceed 25 percent of the LEL for methane in facility structures*…"
- 20921 (a) (1) requires that "…*The concentration of methane gas must not exceed 1.25% by volume in air within on-site structures*…"
- 20931(a) "…monitoring network design *shall include provisions for monitoring on site structures*, including but not limited to buildings, subsurface vaults, utilities or other areas where potential gas buildup would be of concern…"
- 20931(c) "…Structures located on top of the waste disposal area *shall be monitored on a continuous basis*.."
- 20934 (a)(1) "…monitoring reports shall include: (1) the *concentrations of the methane….within each on-site structure*…"
- 20937 (a)(3) "…the documentation of date, time, barometric pressure, atmospheric pressure, general weather conditions and probe pressures…"
- 20937 Control (d) "…When the results of monitoring in on site structures indicate levels in excess of those specified in Section 20923(a), the operator *shall take appropriate action to mitigate the effects of landfill gas accumulation in on site structures*, and public health and safety, shall include one or more of the following*:…(4) Alarms, …(5) Ignition source control…(7) Ventilation*…"
- 27 CCR 21190 a) Proposed PCLUs shall be designed and maintained to: …(3) *prevent landfill gas explosions…"*
- 27 CCR 21190 e) "…Construction of structural improvements on top of landfill areas…shall meet the following conditions:…(1) *automatic methane gas sensors, designed to trigger an audible alarm when methane concentrations are detected, shall be installed in all buildings*…"
- 27 CCR 21190 e) (8) *periodic methane gas monitoring shall be conducted inside all buildings*…"

California regulations regarding post closure land uses of former landfills and disposal sites (27 CCR 21190) require local officials to approve such uses and to include provisions to protect structures from landfill gas migration. These protections may include: under foundation gas-barrier systems, active and passive gas collection and control systems, continuous monitoring of structures, facility active ventilation systems, alarm systems, etc. (http://www.ciwmb.ca.gov/Regulations/Title27/ch3sb5.htm#Article2).

The ***County of Los Angeles Building Code*** includes provisions that prohibit the construction of structures within 1,000 feet of a disposal site, unless a report is prepared by a licensed civil engineer that provides recommendations to protect structures from landfill gas migration hazards (http://municipalcodes.lexisnexis.com/codes/lacounty/).

> **110.3 Fills Containing Decomposable Material.** Permits shall not be issued for buildings or structures regulated by this Code within 1,000 feet (304.8 m) of fills containing rubbish or other decomposable material unless the fill is isolated by approved natural or artificial protective systems or unless designed according to the recommendation contained in a report prepared by a licensed civil engineer. Such report shall contain a description of the investigation, study and recommendation to minimize the possible intrusion, and to prevent the accumulation of explosive concentrations of decomposition gases within or under enclosed portions of such building or structure. At the time of the final inspection, the civil engineer shall furnish a signed statement attesting that the building or structure has been constructed in accordance with the civil engineer's recommendations as to decomposition gases required herein. Buildings or structures regulated by this Code shall not be constructed on fills containing rubbish or other decomposable material unless provision is made to prevent damage to structure, floors, underground piping and utilities due to uneven settlement of the fill. One-story, detached light-frame accessory structures not intended or used for human occupancy and not exceeding 400 square feet (37.2 m^2) in gross floor area nor 12 feet (3658 mm) in building height may be constructed without special provision for foundation stability. (Ord. 2007-0108 § 2 (part), 2007; Ord. 95-0065 § 3 (part), 1995.)

3. Continuous Monitoring System Overview

A continuous gas monitoring system or fixed gas detection system generally includes: combustible gas sensors, sensor cable (unless using wireless transmitters and receivers), controllers, data acquisition hardware (memory) and programmable logic control software (see Figure 2). All of these components are commercially-available off-the-shelf, and have several manufacturers. Most of the equipment can be purchased directly from the manufacturer or through an authorized distributor. Generally continuous gas monitoring systems are not commercially available as complete "turn-key" systems and will need to be designed and installed by qualified consultants and contractors.

Continuous Gas Monitoring Systems should be planned, designed and coordinated by appropriately licensed engineering consultants familiar with landfills and landfill gas monitoring and control systems. System installation can be performed by qualified industrial controls, building automation controls, or Heating, Ventilation and Air Conditioning (HVAC), and industrial electrical contractors. System calibration and programming should be performed by qualified consultants or industrial controls contractors.

A consultant should prepare a work plan and design the system considering previous landfill investigation reports and historical gas monitoring data, building and utility design plans and in consultation with owners and regulators.

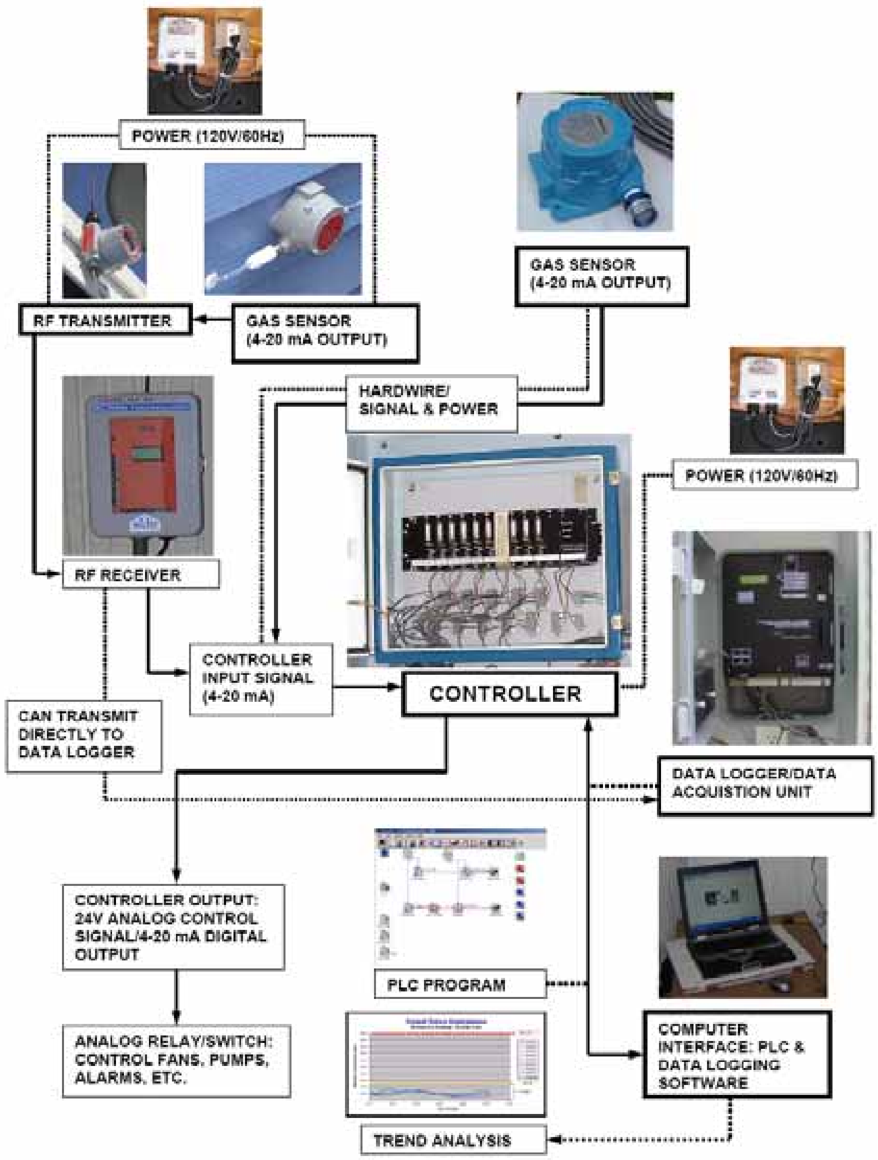

Figure 2: Overview of Continuous Gas Monitoring System

4. Landfill Gas Migration Routes and Planning the Location of Sensors

Landfill gas migration is dependent on several variables, however subsurface geology, surface and subsurface development, and building structure and foundation characteristics are probably the most important considerations in locating sensors (Figure 3).   Landfills located in geologic units containing gravels and sands are susceptible to lateral gas migration (Anderson, Young, Christ 1996). Former gravel pits filled in with municipal solid waste are likely to have lateral gas migration.   Surface and subsurface development, e.g. building foundations, paved areas, subsurface drainage, utility corridors, and access vaults, etc. can be pathways for lateral gas migration.

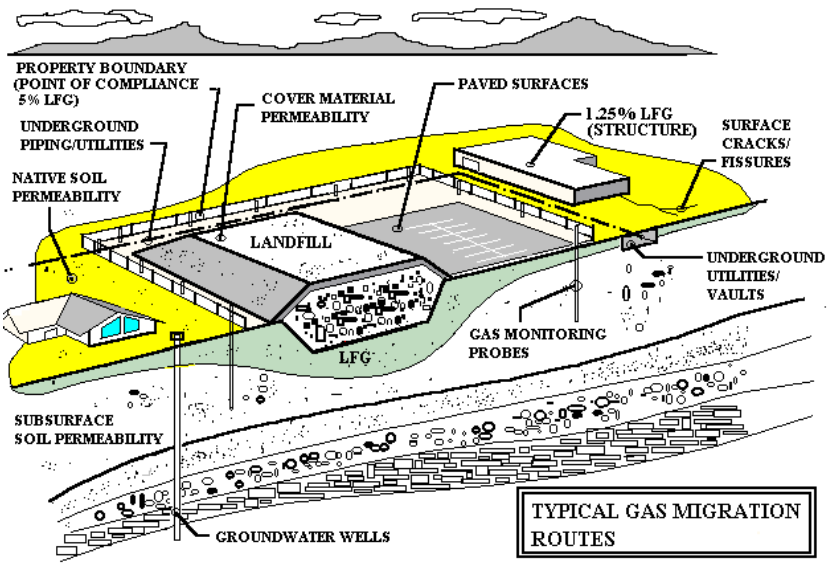

Figure 3: Landfill Gas Migration Pathways

In general, spaces that have occupancy or are accessible where explosive levels of gas or oxygen deficient environments may occur, e.g. potential confined space hazard, should be considered high priority locations for placing gas sensors. Personnel who work on water wells, underground utilities, excavations, etc. may be at risk from gas migration and sensor placement in these locations may be warranted.

Gas migration into structures constructed on top of waste may occur, even if engineered precautions (utility boots, membranes, well bore seals, utility seals, etc.) are taken, because differential settlement is difficult to predict for the life of the structure, e.g. predicting areas of settlement due to surface loading as well as waste consolidation due to inherent waste properties (decomposable content, voids, compaction, etc). The key is to identify susceptible areas and spaces and to monitor them for landfill gas migration.

The following factors should be considered in locating gas sensors:

- Confined spaces near a landfill where a 5-15 percent Lower Explosive Limit (LEL)-Upper Explosive Limit (UEL) condition, e.g. utility systems: manholes, vaults, utility boxes and subsurface trenches, storm drains, water, and electrical distribution in the vicinity or through the disposal area (note: an oxygen sensor should be included in addition to a combustible gas sensor to detect oxygen-deficient environments);

- Enclosed, Habitable or Occupied Building Structures on or within 1,000 feet of the landfill (homes, buildings, warehouses, outdoor restrooms, etc.). Note: 1,000-foot distance requirement is established in regulation (27 CCR Section 20923);
- Within Buildings: Basements, subfloors and raised foundations, utility closets, mechanical rooms, bathrooms (utility penetrations), other spaces adjacent to the foundation, and penetrations through the foundation
- Avoid placing sensors near heating, ventilation and air conditioning (HVAC) system diffusers, return-air grills, etc.
- Sensors should not be placed in areas where combustible liquids and gases, e.g. paints, solvents, cleaners, etc. are normally used.
- Buildings located over fill: some building foundations constructed over disposal areas may be compromised by differential settlement; cracks in foundations should be monitored for landfill gas; buildings with sub-slab venting systems should have monitoring within the venting layer (a vault box) or a sensor placed in the vent stack (piping conveyance used to vent foundation to atmosphere).

5. Continuous Gas Monitoring System Operation

Combustible gas sensors using Catalytic Bead or Infrared Analyzer technology transmit a 4-20 milli-ampere (mA) signal that is proportional to a minimum and maximum value for a given calibration gas. Generally the maximum concentration or “span” is the lower explosive limit or 5 percent. At a concentration of 5 percent the sensor will send a 20 mA signal; the minimum value for gas is generally a zero calibration gas (oxygen or air) which contains no detectable combustible gas concentrations; the signal for “zero” gas is 4 mA.

The 4-20 mA signal is then either transmitted by wire or converted to a radio frequency signal using a wireless transmitter and sent back to a receiver (for wireless) and controller or data acquisition hardware. The controller and data acquisition hardware are programmed using a PC and programmable logic control software (PLC).

The PLC software allows a user to specify the time and frequency of measurements to be taken and operations to process signal and record to memory for each sensor. Generally data is recorded as concentration in parts per million (ppm); thus gas concentrations will be recorded from 0 ppm (0 percent) to 50,000 ppm (5 percent). A certain amount of signal drift can be expected and a range (known as a plus or minus band) should be documented (based on readings over a period) to qualify the data when reporting.

The PLC software allows a user to define process instructions which can include actuating alarms or ventilation systems based on a measured condition. Thus, if a sensor detected a gas concentration of 1.25 percent, the PLC instructions could require that the measurement be recorded, an audible alarm sounded, and a telephone dial-up system notification be performed. The PLC instructions could also include turning on the building ventilation systems until the same sensor measures less than 1,000 ppm.

6. Sensors

Combustible Gas Sensors are used to detect and measure concentrations of combustible gas. Combustible gases can include methane, butane, propane, pentane and other petroleum-based compounds. Generally sensors are calibrated to a known source and concentration of combustible gas, such as methane. Calibration kits for methane are commercially available in 5 percent and 100 percent concentrations. Combustible gas sensors use either a Catalytic Bead or Infrared Analyzer sensor technology that utilize an electric circuit which measures physical properties of the gas to determine changes in gas concentrations.

a. Catalytic Bead Sensor

In a catalytic detector (see Figure 4), two ceramic beads are heated to ~450°C (General Monitors Corp, 2005). One is activated by a catalytic material that oxidizes the gas and forms additional heat that is detected by measuring the resistance of a platinum coil. The bridge current of a Wheatstone bridge with a second, deactivated bead as reference is approximately proportional to gas concentration at the lower explosive limit. Many portable instruments use a Catalytic Bead sensor, however the use of this sensor requires the presence of oxygen in order to combust the gas. For some landfill gas measurement applications, such as landfill gas extraction wells, where oxygen may be absent, catalytic bead sensors may not accurately measure the concentration of combustible methane gas present. Catalytic Bead sensor performance can become degraded over time due to environmental contaminants that may react with the bead's ceramic substrate.

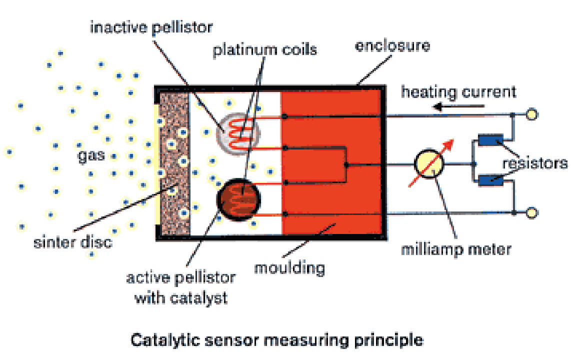

Figure 4. Catalytic Sensor

b. Infrared Analyzer

A combustible gas sensor with infrared analyzer technology (or IR technology), measures concentrations of a gas by using an infrared source and an infrared detector (General Monitors Corp., 2005). The amount of infrared energy absorbed by the gas is measured by the detector and can be converted to a direct measurement of gas concentration. A sensor using infrared analyzer technology does not require the presence of oxygen to detect combustible gas and thus can accurately measure combustible gases in low-oxygen environments, e.g. landfill gas extraction wells that may, depending on anaerobic conditions, contain 60 percent methane, 38 percent carbon dioxide, 1 percent trace volatile organics and less than 1 percent oxygen.

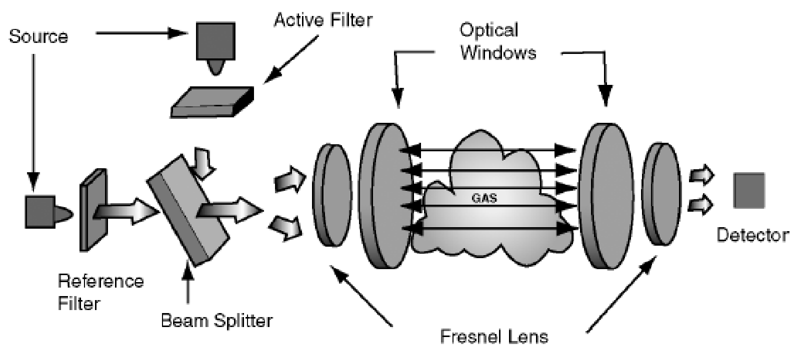

Figure 5. In an infrared analyzer the measured gas absorbs infrared energy from infrared source; an infrared detector detects the amount of infrared energy absorbed.

7. Digital and Analog Controllers

A controller is an electrical or electro-mechanical device that is used to control processes in which a parameter is measured and a process operation is performed using a predetermined condition or "set-point." Analog controllers such as thermostat controllers are used in heating, ventilation, and air-conditioning systems to sense room temperatures and actuate air conditioning equipment, e.g. turn-on compressor and fan unit. Other controller applications may include sensing liquid levels in tanks and turning on pump systems (using an electro-mechanical relay to turn on the motor control station for a pump), at specified liquid levels. The lawn sprinkler in your home may be controlled using a programmable irrigation controller which allows a user to specify the time of day and duration of irrigation. The controller receives the input instructions from the user and turns on the irrigation system by sending a control voltage to a solenoid valve, which opens (or closes) the water supply line.

Modern controllers may be PC systems with Programmable Logic Control software interfaced with an Integrated Circuit Control Board that allows input conditions to be measured and output conditions to be specified using programmed instructions.

In the case of landfill gas detection, controllers can be used to receive input measurements from gas sensors and perform operations such as saving measurements to memory at a specified time and frequency (for time-trend analysis and enforcement data), or to send an output signal to actuate an audible or silent alarm or to turn on a building ventilation system or gas control system.

Controllers vary in price based on number of channels* and features, but because there are many manufacturers of controllers and controllers for a variety of applications (e.g. HVAC, Wastewater, Water and Industrial Process Control, etc.), pricing is generally competitive. Controllers generally require a 120 Volt/60Hz power supply which is stepped-down using internal transformers for control voltages (24V control system). Controllers generally cost from $500-$10,000 depending on number of channels and features. For example a 10-channel programmable industrial process controller can range in price from $3,000 to $10,000. *Note: A channel represents each sensor 4-20 mA input; 10-channels can receive input from 10 sensors.

8. Data Acquisition Systems

Data acquisition systems are electronic memory storage hardware and software devices for storing process measurement data in the field at the location where data is being collected. A data logger allows output measurements from sensors to be stored in electronic memory. Generally the gas concentration data is converted from the 4-20 mA output signal from a sensor to parts per million (ppm). The data is stored to a data logger as ppm measurements. The data acquisition or data logger hardware may come with programmable logic control software that allows a user to provide program instructions for processing input sensor measurements and recording these measurements at specified times and frequencies. Data acquisition systems require a 120-Volt/60 Hz power supply for operation. Data acquisition systems can be monitored and downloaded remotely using a phone modem. Data acquisition systems are commercially available by several manufacturers for a multitude of applications and are competitively priced from $1,000 up to $5,000 depending on qualities and features (memory size and input channels are generally the most significant cost factor).

9. Continuous Gas Monitoring System Installation

A continuous gas monitoring system should be designed based on site specific conditions (subsurface geology and facility and utility construction) and historical gas monitoring data. Gas concentration measurements taken from gas monitoring probes provide an understanding of gas migration pathways and areas of higher gas concentrations, especially in shallow soils. Utility corridors, wells, and maintenance vaults should also be considered in determining sensor placement. Finally a building foundation, utility penetrations through the foundation, as well as an understanding of any potential foundation flaws, e.g. settlement cracks, should be considered in locating sensors. Other installation considerations include power source locations, telephone utility locations, length of cable runs (due to voltage drop specifications) and the cost of wiring installation.

It is often times advantageous to “cluster” sensors in areas to minimize wiring costs, e.g. using a common trench or conduit. Wireless transmitters and receiver units can be advantageous if several areas are to be monitored at significant distance (and/or with difficult trenching conditions, e.g. high density subsurface utilities), although the cost per sensor increases. Wireless transmitters and receiver units, which convert a sensor's 4-20 mA signal into a radio frequency "data packet," can be used at distance of up to one mile line of sight. Wireless transmitters and receivers can also be used within a building, although signal degradation may occur in buildings which contain metals (prefabricated metal buildings) that may interfere with radio frequencies.

Continuous Gas Monitoring Systems should be designed by a registered civil, mechanical, electrical, or controls engineer, with experience in landfill gas monitoring and control and/or in facility and utility construction on or near landfills and disposal sites. Subcontractors performing installation of continuous monitoring system components should be licensed electrical, mechanical, or industrial controls contractors. Work should be overseen and construction quality assurance and control performed by the design consultant. Operation, calibration and maintenance of the system should be performed by the design consultant with field staff trained on the specific equipment and familiar with component manufacturer's operations and maintenance requirements.

The preparation of a work plan by the design consultant, which includes site background information, a gas-sensor location plan, system component installation specifications and details, operations and maintenance (calibration) procedures, equipment specifications, etc. is critical to the successful planning and installation of a continuous gas monitoring system.

10. Continuous Gas Monitoring System Operations and Maintenance

An operation and maintenance plan should be prepared by the consultant to ensure that the system is receiving power, the sensors are properly calibrated and replaced as necessary, gas concentration data is downloaded and system components periodically checked to ensure they are functioning properly. An owner may not have the expertise to be able to operate and maintain the system and should consider retaining a qualified consultant. Measurement data should be checked daily in the first two weeks of operations; and weekly in the following six weeks of operation to ensure that drifting is not occurring or other anomalous condition caused by factors other than the measurement of combustible gas. Quarterly system calibration and inspection should be the rule after the first quarter of operation.

When gas migration events are detected, especially those that exceed regulatory thresholds, additional calibration checks are warranted to check measurements to ensure data quality. The most important period of operation is the one-year period following installation. If gas migration is going to be detected, it is most likely going to be detected during this period (although there are many factors which can affect landfill gas generation and migration). Operations and maintenance of a continuous gas monitoring system are critical to the effectiveness of the system as a mitigation measure to protect public health and safety from gas migration from former landfills and disposal sites.

11. Case Study 1: Warehouse on Former Sacramento, California Landfill

A commercial warehouse located in Sacramento, California, was constructed over a former landfill in 1982. During construction of the piling foundation for the warehouse, a worker trying to retrieve a drilling auger from one of the piling holes was overcome by low oxygen levels and fell into the hole.

Firefighters were unable to rescue the individual, who died of asphyxiation.   In 1992, a decade after construction of the warehouse, local and State officials detected concentrations of combustible gas from settlement cracks in the warehouse floor which exceeded the lower explosive limit (5 percent methane by volume in air). The owner was required to take corrective actions to mitigate explosive gas conditions within the warehouse, which included venting a subfloor area and also installing a gas-alarm system to continuously monitor the warehouse for explosive levels of combustible gas. In 2006, local officials discovered that the owner had discontinued use of the gas-alarm system and required the owner to allow State officials to install a continuous landfill gas monitoring system in the warehouse.

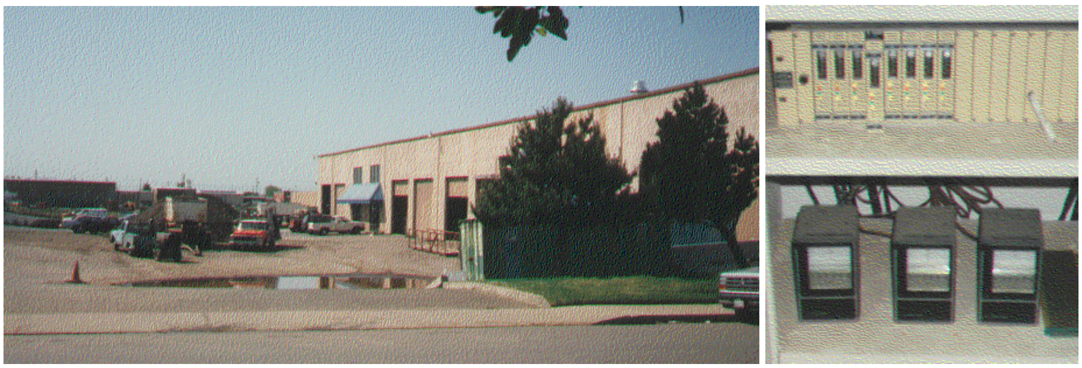

Figure 6: Sacramento Warehouse Constructed on a Former Landfill; Continuous Monitoring System

The CIA program designed and installed a six-sensor continuous gas monitoring system with a controller, data acquisition system, and programmable logic control software. The system used catalytic bead type sensors which were hard-wired to the controller for power and signal. The system was calibrated initially and quarterly and readings were downloaded on a monthly basis.   The system used programmable logic control to continuously collect data. Gas concentrations were sampled every 15 minutes and the highest measurement recorded from each hour’s measurements. The time-trend graph shown in Figure 7 depicts the results of monitoring four months after installation of the system:

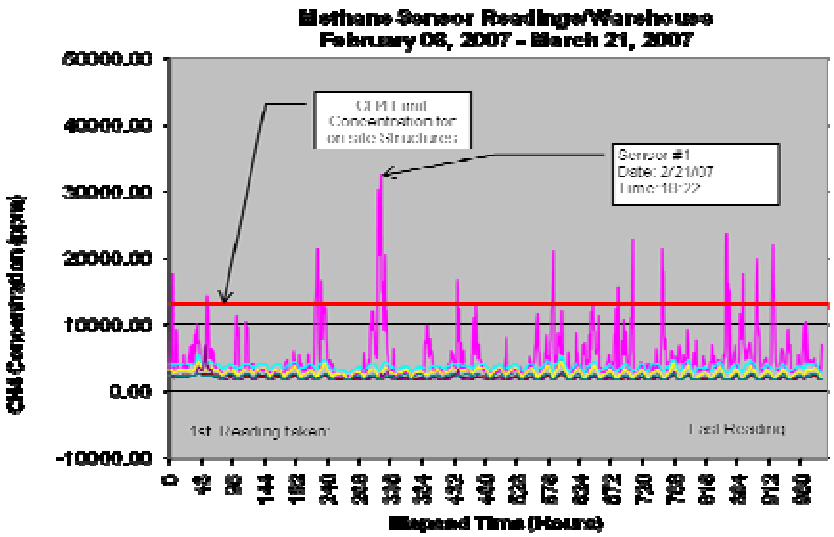

Figure 7: Gas Concentration Versus Time Graph

As shown by the graph, Sensor No. 1 had measured several "events" exceeding the 1.25 percent regulatory threshold concentration, which required the owner to take corrective actions to mitigate. The owner proposed and implemented several mitigation measures, including installing active ventilation in the building, continuing to monitor the building as part of the mitigation, eliminating any ignition sources, and limiting building occupancy and uses. In addition, landfill gas control measures were being taken by the multiple property owners of the landfill to decrease gas concentrations in perimeter wells, which were exceeding the 5 percent regulatory concentration threshold.

12. Case Study 2: City of Newport Beach Former Landfill

The Orange County Environmental Health Department requested assistance from the Closed, Illegal and Abandoned Site program in investigating landfill gas migration issues at a former Newport Beach landfill. Condominiums had been developed adjacent to, and on top of, the former landfill (Figure 8). The site was a gravel mining operation in the 1940s and was used as a municipal solid waste landfill during the 1950s-1960s. In the early 1970s, the site was developed into residential condominium units. Portions of the site were filled and graded to accommodate the condominiums, streets, and common areas. Most of the disposal site footprint was used as a park with trails and was landscaped. A landfill gas collection and venting system was installed as part of the development; operation and maintenance of the gas collection system was included as a responsibility of the homeowners association. The city of Newport Beach was responsible for monitoring perimeter gas monitoring wells at the site. In the 1990s, Orange County officials issued violations to the homeowners association for property boundary gas monitoring wells that were exceeding 5 percent.

Figure 8: Aerial Photo of Condominium Development in Southern California; Direct Push Equipment Used During Investigation

In 2001, Orange County officials requested assistance from the CIA program to investigate gas migration issues at the site. A landfill gas investigation work plan was developed and coordinated by program staff, which included using direct push equipment to sample over 50 grid-locations throughout the development (Figure 8). The purpose was to perform an in-depth phase I investigation, e.g. collect all previous reports and data for the site, and verify the vertical and horizontal extents of waste. During the investigation, gas sampling using combustible gas instruments was performed and documented for each grid-location. A gas concentration gradient map was developed based on measurements taken at each location. T.O.-15 analysis and ASTM 1946 fixed gas analysis were performed at locations where methane was measured at 1 percent or greater by volume in air. During the investigation it was discovered that a portion of the development had been constructed over a portion of the landfill. A second phase of the investigation was developed and coordinated to install a continuous gas monitoring system adjacent to the concrete slab foundations of the condominium units built over fill.

Eight combustible gas sensors (catalytic bead) were located in clusters in areas where significant concentrations of landfill gas were measured. One of the areas measured contained over 1,500 parts per million hydrogen-sulfide and had concentration of gas exceeding 50 percent methane by volume in air. A shallow, 3-foot deep subsurface-vault was designed (Figure 9), in which the gas sensors were placed. The sensors were hardwired to a centrally located controller and data logger on one of the condominium buildings. Power and telephone connections were made to the controller from existing building utilities.

An electrician who normally worked for the condominium development was subcontracted to perform the electrical connections required. Due to the dense amount of subsurface utilities at the site (landscape irrigation pipe, storm drains, electrical and gas utilities, etc.), excavation of a shallow 24-inch deep trench to run conduit and cable for the sensors was time-intensive and a significant expense in implementing the continuous monitoring system (Figure 9). The total cost of equipment was $10,400 (eight catalytic bead sensors @ $1,000 each, 1 each 8-channel controller @ $2,500 and 1 each data logger @ $1,500) and $15,000 for installation and landscaping costs. The system sensors were calibrated initially using a 5 percent calibration gas and the data logger programmed using programmable logic control (PLC) software to take continuous measurements every 15 minutes. The data logger was downloaded remotely (phone modem) each month and imported into Microsoft Excel for analysis using time-trend graphs. The results of one year of monitoring indicated that no measurements were documented that exceeded the 1.25 percent concentration for structures.

Figure 9: Trench for Sensor Cable; Sensor Vault adjacent to Condominium; Sensor Calibration

13. Case Study 3: Long Beach Mobile Home Park

The Los Angeles County Environmental Health Department requested the assistance of the Closed, Illegal and Abandoned Site program in investigating a former disposal site in Long Beach, California. The site had been developed into a mobile home park in the 1970s (Figure 10) and county officials were concerned about potential landfill gas migration into the mobile homes. The site was adjacent to a former oil field and was used to dispose of drill cuttings in the 1920s. From the 1930-1950s, the site accepted industrial and municipal waste. The disposal site ceased operations in the 1950s and the mobile home park, a yacht harbor, a hotel, and restaurant were developed on the site in the 1970s.

Figure 10: Aerial Photo of Long Beach Mobile Home Park; Direct-Push Equipment; Gas Screening & Sampling

In 1976, a mobile home explosion killed a person who was welding under one of the units. The CIA program conducted a soil-gas investigation by using direct push equipment to investigate and install more than 50 sites in the park. Probes were monitored monthly for a period of 12 months. The average concentrations of methane was approximately 50 percent by volume in air (Figure 11).

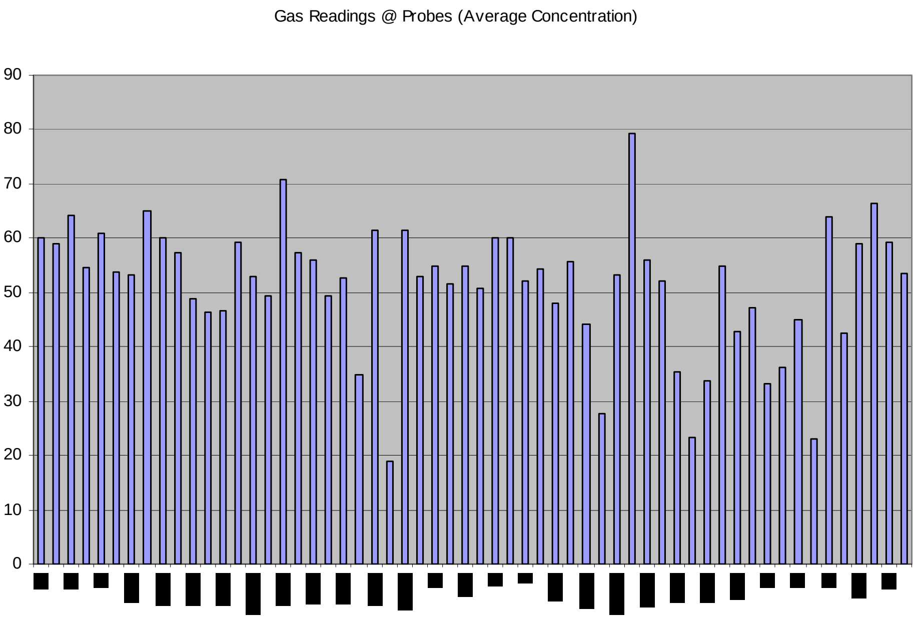

Figure 11: Gas Concentration Measurements from 50 gas sampling points

The CIA program presented the findings of the investigation to the mobile home park owners and developed a continuous gas monitoring plan, which included selecting mobile homes in the areas of the highest gas concentration measurements. Residents were solicited for voluntary monitoring of their mobile home. Many of the mobile homes had “skirts” constructed that enclosed the space beneath the mobile home, potentially creating conditions that would allow the accumulation of landfill gas migrating through cracks in the cover.

The CIA program designed a continuous gas monitoring system that included eight gas sensors which utilized infrared analyzer technology. Also, program staff, based on several configurations and designs, determined that the use of wire cable for connecting the sensors to the data logger unit would require trenching through waste in areas with dense underground utility systems. The length of the cable runs and time and expense of trenching caused program staff to consider the use of wireless transmitters and a receiver unit, which could transmit the sensors 4-20 mA data to the data logger. Based on initial calculations, the cost of installing wire cable for the sensors would have been in excess of $20,000. The additional cost of wireless transmitters and the receiver unit was $15,000. Each sensor was equipped with a wireless transmitter unit and required a power source. The system was installed at eight mobile home locations throughout the park and sensors were mounted in the skirts of the selected trailers. The receiver unit and data logger were placed in one of the park’s permanent structures (a laundry facility). The system was calibrated initially and quarterly and the system was programmed, using programmable logic control software to measure and continuously collect gas concentrations every 15 minutes. The system data was downloaded monthly and summary reports provided to the county (Figure 12).

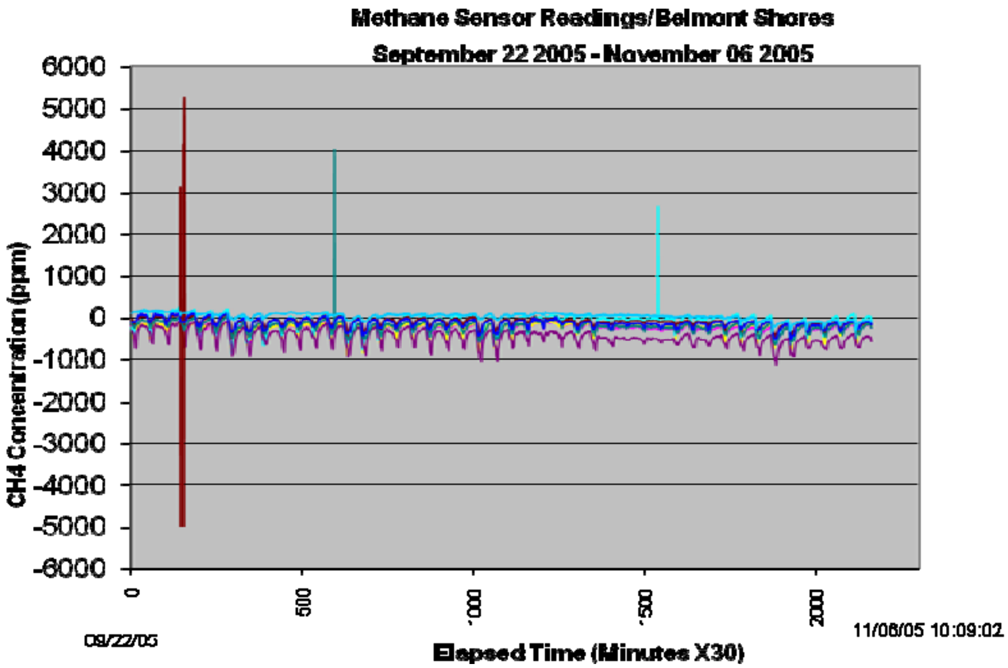

Figure 12: Continuous Gas Monitoring Data for 8 gas sensors located in a Long Beach mobile home park

After 12 months of monitoring, there were no measurements taken that exceeded the regulatory threshold of 1.25 percent concentration by volume in air. As a precautionary measure, the park management provided a wall-mounted combustible gas detector and alarm unit to each resident in the park.

14. Conclusions and Lessons Learned

Continuous landfill gas monitoring systems, when properly designed, installed, operated, and maintained, provide a cost-effective mitigation measure to protect public health and safety from landfill gas migration from former landfills and disposal sites. Continuous monitoring systems can be used to automate and control building ventilation and alarm systems to mitigate explosive gas conditions. Continuous monitoring systems can provide an interim or stop-gap mitigation to protect public health and safety while conventional landfill gas control remediation measures are being investigated, designed, and constructed.

Continuous monitoring systems can provide the necessary data to justify gas collection and control at former landfills and disposal sites. Compared to the costs (more than $500,000) and timing (more than one year) for many landfill gas remedial actions, e.g. installation and operation of gas monitoring, collection and control systems, the installation and operation of a continuous gas monitoring system (less than $30,000) is the most effective stop-gap mitigation measure that can be taken by State and local officials to ensure that public health and safety are protected. Continuous monitoring systems can also provide a method of verifying the effectiveness of conventional gas collection and control systems used at the landfill to control migrating landfill gas.

Data collected from continuous gas monitoring systems allows public health officials to determine if an indoor gas migration condition exists that represents a threat to public health and safety and requires landfill gas remedial controls. Continuous monitoring systems can be used by owners to determine where hazardous conditions may exist and take appropriate actions to mitigate the hazard. Owners can also use the continuous monitoring system to automate ventilation and alarm systems based on specified levels (generally 1.25 percent methane gas concentrations).

Continuous gas monitoring systems should be designed and installed by qualified consultants and contractors with experience in the fields of landfill gas migration remediation and industrial/building automation controls. A work plan should be prepared and coordinated by the consultant that provides back ground information, component location plan, installation, operations and maintenance specifications. The content of the work plan should be easily converted into a contract bid document and cost estimate (scope of work, and plans and specifications). The work plan should be coordinated with State and local officials, property owners, consultants, equipment manufacturers, and subcontractors to ensure that the work will meet all stakeholder requirements.

Infrared Analyzer (IR) technology is the preferred sensor technology because it can operate in low-oxygen environments and harsh environments that may contaminate catalytic bead sensors, as well as sensor reliability (both in terms of sensor replacement and maintaining calibration). Sensors should be UL certified and have explosion-proof housings (e.g. intrinsically safe).

Wireless transmitters and receivers can reliably transmit 4-20 mA sensor information up to one mile line of sight (greater distances with repeaters) and can solve difficult hard-wire layout conditions (e.g. buildings, developed hardscaped, and landscaped areas with dense subsurface utilities, etc.) The cost for more expensive wireless equipment may be offset by difficult wiring layout conditions that would require difficult trenching or conduit runs and facility and utility repair and replacement costs.

Continuous gas monitoring system equipment components should be function-checked and sensors calibrated, initially, daily for the first week, monthly for the first six months and quarterly thereafter. A check should be performed as well after the first event is recorded. A follow-up should be performed on each monthly download report with the operator for events that are measured by the system to check conditions around the sensors for those dates to check for false positives (e.g. vehicles operating in the vicinity, painting or cleaning using volatile compounds, etc.)

Based on Board/Local Enforcement Agency experience at the former La Veta disposal site in Orange County, it is recommended that continuous gas monitoring systems be designed and installed such that audible alarms are triggered whenever combustible gas is detected at or above a set level (1.25 percent or lower) by any sensor. The occupants of a structure should have clear instructions and training of what to do in this case. Occupants also should have maintenance contractor contact information if they suspect any component of the continuous gas monitoring system has malfunctioned.

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